ARSENIC

FACT SHEET

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumptions; Raw Water Composition; Total Plant Costs; and WaTER Program.

1. CONTAMINANT DATA

A. Chemical Data: Arsenic (As), inorganic element, semi-metal, stable and sparingly soluble, atomic number 33, atomic weight 74.92. Inorganic oxidation states (in water): +3 (Arsenite-most toxic) and +5 (Arsenate). As has no taste, smell, or color in water.
B. Source in Nature: As is a naturally occurring element found in soils, surface water, and groundwater, with the highest natural concentrations of As usually found in areas of geothermal activity. However, very little is known about the geologic, hydrologic, and biogeochemical conditions which favor dissolution of arsenic into groundwaters. As is found in varying levels in most food groups with the major sources being marine plants and shellfish. In industry, As is used in the production of pesticides and herbicides, from cotton and wool processing, as a wood preservative, a feed additive, in various metal alloys, and in mining. As can result from pesticide runoff; from seepages from hazardous waste sites; and from areas near cemetaries where burials were conducted from about 1880 to 1910 when As was used as an embalming fluid. As is ingested by either drinking contaminated water, eating food that has been washed in the water, or ingestion in small doses by way of the human food chain.
C. SDWA Limits: MCL for As is 0.01 mg/L. MCLG is 0 mg/L for drinking water.
D. Health Effects of Contamination: As is a known carcinogen and poisoning can be either acute or chronic. As is a teratogen, meaning it can enter the metabolic system of unborn babies. Acute poisoning results from ingestion of large quantities of As at one time resulting in stomach pain, nausea, vomiting, or diarrhea which may lead to shock, coma, and even death. Chronic poisoning occurs over long periods of time often resulting in skin lesions, thickening or discoloration of the skin, and numbness in the feet and hands (neuritis). As poisoning has been linked to higher rates of cancer of the lungs, bladder, kidney, liver, and skin. Young children, the elderly, unborn babies, and people with long-term illnesses are at greater risk of As poisoning.

2. REMOVAL TECHNIQUES

Optimal As removal is dependent on many individual water characterisitics, including source water pH, TDS, sulfides, other salts, quantity of water to treat, and amount of As present. As^{+5} is most effectively removed, therefore As^{+3} may be converted through preoxidation with Cl_2, $FeCl_3$, or $KMnO_4$ to As^{+5}. Preoxidation with Cl_2 may create undesireable concentrations of disinfection by-products.
A. USEPA BAT: Coagulation and filtration; lime softening; reverse osmosis; or activated alumina.
! Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Benefits: low capital costs for proven, reliable process. Limitations: operator care required with chemical usage; sludge disposal.
! Lime softening for As treatment uses two types of chemical additions. First, $Ca(OH)_2$ is added in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness. Next, Na_2CO_3 is added to precipitate noncarbonate hardness. Benefits: proven and reliable. Limitations: operator care required with chemical usage; sludge disposal.
! RO uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids, to pass through the membrane. Benefits: produces highest As removal, along with high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
! AA uses extremely porous and highly adsorptive aluminum ore media to adsorb As^{+5}. Benefits: containment of As^{+5} in adsorption bed. Limitations: highly selective to As^{+5} resulting in frequent regeneration; results in creation of hazardous waste requiring disposal. AA cost curves will be included in a future revision.
B. Alternative Methods of Treatment: Ion exchange can remove As however efficieny is affected by SO_4^{-2}, TDS, Se, F^-, and NO_3^-. Electrodialysis reversal can achieve removal of As at about 80%. Nanofiltration can achieve removal of As at about 90%. In the presence of dissolved Fe and Mg, As will co-precipitate and can be removed with Greensand or other specialized Fe and Mg filtration media.
C. Safety and Health Requirements for Treatment Processes: Personnel involved with demineralization treatment processes should be aware of the chemicals being used (MSDS information), the electrical shock hazards, and the hydraulic pressures required to operate the equipment. General industry safety, health, and self protection practices should be followed, including proper use of tools.

3. BAT PROCESS DESCRIPTION AND COST DATA

General Assumptions: Refer to: Raw Water Composition Fact Sheet for ionic concentrations; and Cost Assumptions Fact Sheet for cost index data and process assumptions. All costs are based on *ENR*, PPI, and BLS cost indices for March 2001. General sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal are not included.

3A. Coagulation and Filtration:

Process - Coagulation and filtration uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation, flocculation, and dual media filtration. Chemical coagulation and flocculation consists of adding a chemical coagulant combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). $Fe_2(SO_4)_3$ has been proven to be the most effective coagulant for As^{+5} removal. Filtration provides final removal by dual media filtering of all floc and suspended solids.

Pretreatment - Preoxidation to convert As^{+3} to As^{+5}. Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required.

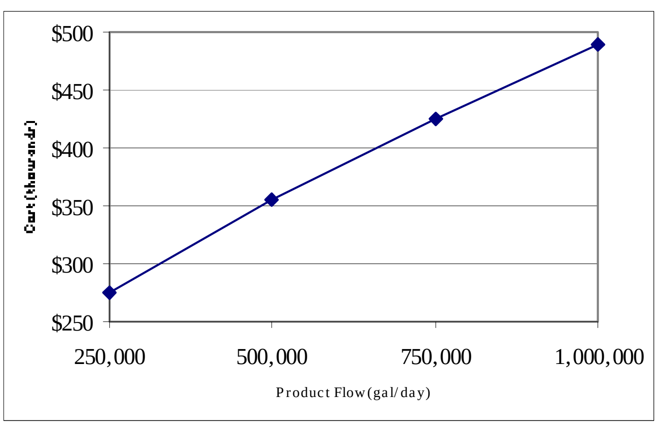
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Routine checks of contaminant buildup in the filter is required, as well as filter backwash. Recharging or clean installation of media is periodically required.

Waste Disposal - Filter backwash and spent material require approved disposal.

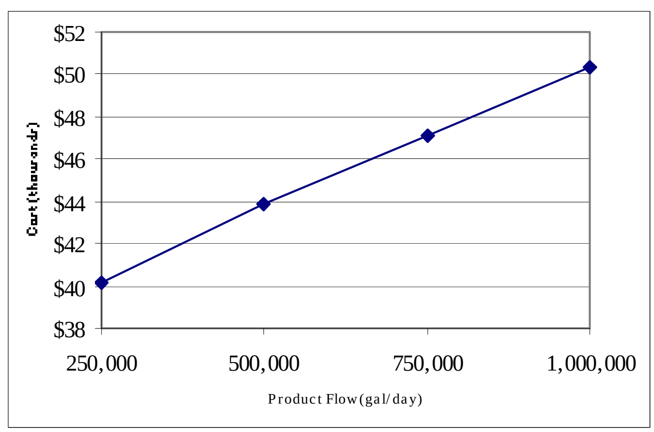
Advantages -
- Lowest capital costs for larger systems.
- Lowest overall operating costs for larger systems.
- Proven and reliable.
- Most effective for As^{+5}.

Disadvantages -
- Not appropriate for smaller systems.
- Operator care required with chemical handling.
- Produces high As-contaminated sludge volume.
- High or low pH reduces treatment efficiency; secondary treatment may be required.

BAT Equipment Cost*



BAT Annual O&M Cost*



*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal. Costs are presented for direct filtration (coagulation and flocculation plus filtration). Costs for coagulation and filtration would be less since flocculation is omitted.

3B. Lime Softening:

Process - Lime softening uses chemical additions followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical additions include $Ca(OH)_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including As, into larger particles), and final clarification occur. In the upflow SCC, the clarified water flows up and over the weirs, while the settled particles are removed by pumping or other collection mechanisms (i.e. filtration).

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required. Optimum pH is about 10.5 or higher.

Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Similar procedures also apply to the sludge disposal return system, which takes the settled sludge from the bottom of the clarifier and conveys it to the dewatering and disposal processes.

Waste Disposal - There are three disposal options for As-contaminated sludges: incineration, landfill, and ocean disposal.

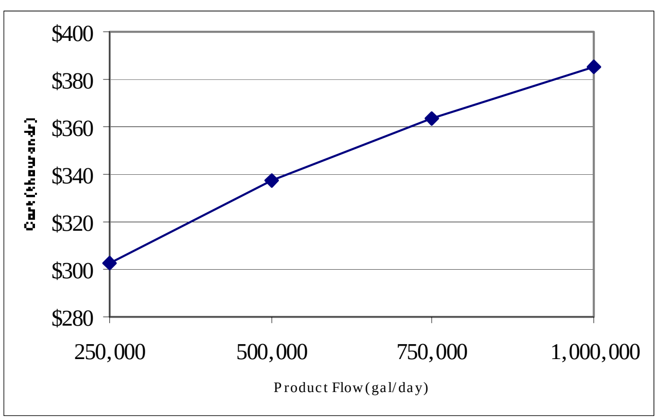
Advantages -

- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

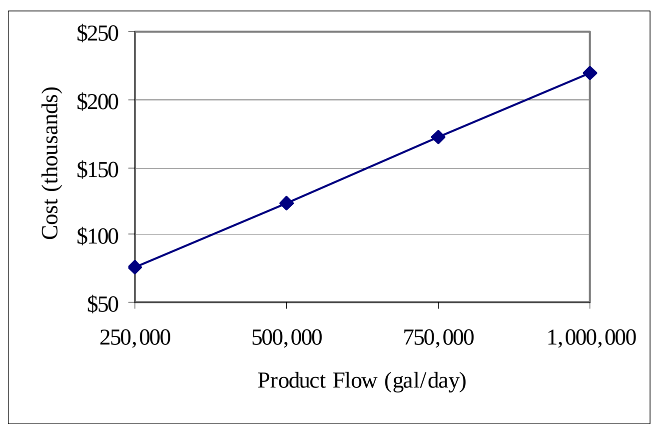
Disadvantages -

- Operator care required with chemical handling.
- Produces high As-contaminated sludge volume.
- Secondary treatment may be required.
- Waters high in sulfate may cause significant interference with removal efficiencies.

BAT Equipment Cost*



BAT Annual O&M Cost*



*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3C. Reverse Osmosis:

Process - RO is a physical process in which contaminants are removed by applying pressure on the feed water to direct it through a semipermeable membrane. The process is the "reverse" of natural osmosis (water diffusion from dilute to concentrated through a semipermeable membrane to equalize ion concentration) as a result of the applied pressure to the concentrated side of the membrane, which overcomes the natural osmotic pressure. RO membranes reject ions based on size and electrical charge. The raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Common RO membrane materials include asymmetric cellulose acetate or polyamide thin film composite. Common membrane construction includes spiral wound or hollow fine fiber. Each material and construction method has specific benefits and limitations depending upon the raw water characteristics and pretreatment. A typical large RO installation includes a high pressure feed pump, parallel 1st and 2nd stage membrane elements (in pressure vessels); valving; and feed, permeate, and concentrate piping. All materials and construction methods require regular maintenance. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance.

Pretreatment - RO requires a careful review of raw water characteristics and pretreatment needs to prevent membranes from fouling, scaling, or other membrane degradation. Removal of suspended solids is necessary to prevent colloidal and bio-fouling, and removal of dissolved solids is necessary to prevent scaling and chemical attack. Large installation pretreatment can include media filters to remove suspended particles; ion exchange softening or antiscalant to remove hardness; temperature and pH adjustment to maintain efficiency; acid to prevent scaling and membrane damage; activated carbon or bisulfite to remove chlorine (postdisinfection may be required); and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles.

Maintenance - Monitor rejection percentage to ensure As removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure with a cleaning agent to remove fouling and scaling. The system is flushed and returned to service. $NaHSO_3$ is a typical caustic cleaner. RO stages are cleaned sequentially. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

Waste Disposal - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

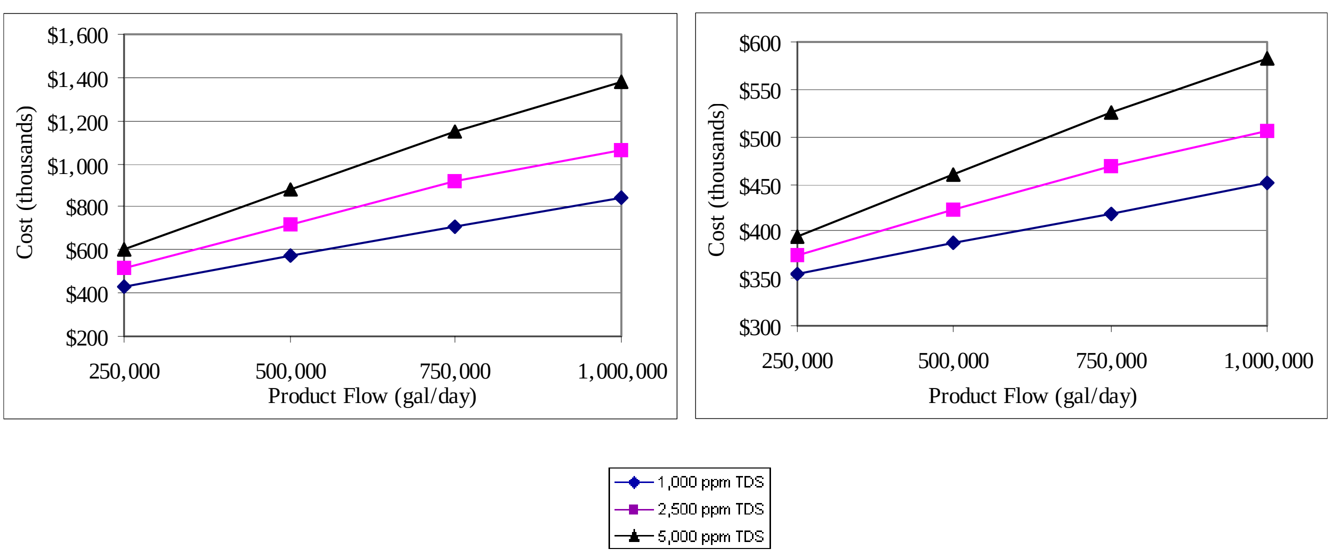
Advantages -

! Produces highest As removal; produces highest quality water.
! Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
! Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages -

! Relatively expensive to install and operate.
! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for As removal.
! Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost* **BAT Annual O&M Cost***



*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3D. Activated Alumina:

Process - AA uses an extremely porous media in a physical/chemical separation process known as adsorption, where molecules adhere to a surface with which they come into contact, due to forces of attraction at the surface. AA is a media made by treating aluminum ore so that it becomes porous and highly adsorptive, and is available in powder, pellet, or granule form. The media is activated by passing oxidizing gases through the material at extremely high temperatures. This activation process produces the pores that result in such high adsorption properties.

Contaminated water is passed through a cartridge or canister of AA. The media adsorbs the contaminants. The adsorption process depends on the following factors: 1) physical properties of the AA, such as method of activation, pore size distribution, and surface area; 2) the chemical/electrical nature of the alumina source or method of activation and the amount of oxygen and hydrogen associated with them, such that as the alumina surfaces become filled the more actively adsorbed contaminants will displace the less actively adsorbed ones; 3) chemical composition and concentration of contaminants effect adsorption, such as size, similarity, and concentration; 4) the temperature and pH of the water, in that adsorption usually increases as temperature and pH decreases; and 5) the flowrate and exposure time to the AA, in that low contaminant concentration and flowrate with extended contact times increase the media life. AA devices include: pour-through for treating small volumes; faucet-mounted (with or without by-pass) for POU; in-line (with or without by-pass) for treating large volumes at several faucets; and high-volume commercial units for treating community water supply systems. Careful selection of alumina to be used is based on the contaminants in the water and manufacturer's recommendations.

Pretreatment - With bacterially unstable waters, filtration and disinfection prior to AA treatment may be required. With high TSS waters, prefiltration may be required. If treatment is based on flowrate, a water meter may be required to register and total flowrates.

Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of media may be required and is based on contaminant type, concentration, and rate of water usage. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145^{o}F) may release the adsorbed chemicals, however this claim is inconclusive. Periodic cleaning with an appropriate regenerant such as $Al_2(SO_4)_3$, acid, and/or caustic will extend media life. With bacterially unstable waters, monitoring for bacterial growth is required because the adsorbed organic chemicals are a food source for some bacteria. Flushing is required if the AA filter is not used for several days, and regular backwashing may be required to prevent bacterial growth. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

Waste Disposal - Backwash/flush water disposal is required if incorporated. Disposal of spent media may be the responsibility of a contractor providing media replacement services.

Advantages -
- ! Well established.
- ! Suitable for some organic chemicals, some pesticides, and THMs.
- ! Suitable for home use, typically inexpensive, with simple filter replacement requirements.
- ! Improves taste and smell; removes chlorine.

Disadvantages -
- ! Effectiveness is based on contaminant type, concentration, and rate of water usage.
- ! Bacteria may grow on alumina surface.
- ! Adequate water flow and pressure required for backwashing/flushing.
- ! Requires careful monitoring.

Costs - The BAT costs curves for AA equipment and annual operation and maintenance are being developed and will be included in a future revision.